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Responding to the challenges of instrumental orchestration through physical and virtual robotics

Lenni Haapasalo [a,*], Peter Samuels [b]

[a] University of Eastern Finland, School of Applied Educational Science and Teacher Education, P.O. Box 111, FI-80101 Joensuu, Finland
[b] Birmingham City University, Academic Skills Centre, City North Campus, Perry Barr, Birmingham B42 2SU, UK

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ABSTRACT

It has been recognised that the general lack of enjoyment of institutional mathematics learning at the secondary level is one of the basic reasons behind the bad reputation of mathematics in society. Increasing students' motivation to learn mathematics through enjoyment and playing, especially in their free time, might therefore be a relevant research focus. This paper considers robot-based investigation spaces for students at the secondary level and the transition from secondary to tertiary level education (or from compulsory to non-compulsory mathematics education) which allow them to explore the facility of real and virtual environments to create behaviours which are both meaningful to them and which naturally motivate a greater use of mathematical language to describe and predict these behaviours more precisely. The value of these environments is assessed from the perspective of the challenges of instrumental orchestration.

1. Introduction

One of the basic milestones of virtual learning environments of mathematics for primary school children was the development of turtle graphics (Papert 1980; Resnick, Ocko, & Papert, 1988), the pedagogy of which was quite 'exhausted' in the 1990's. This debate has now moved on to dynamical geometry programs combined with hand-held technology and is still ongoing intensely (for example, see Aldon et al., 2008; Haapasalo, Zimmermann, & Rehlich, 2004). However, the use of robotic kits with secondary level school students remains uncommon. LEGO Mindstorms NXT robots[1], for example, represent an embodiment of Papert and Harel's (1991) constructionist pedagogy, which proposes a form of constructivism (von Glasersfeld, 1991) in which students learn as they construct physical objects. Most published uses of these robots in secondary and tertiary education so far have been for computing (for example, see Mosley and Kline, 2006) or engineering (for example, see Adams and Turner, 2008) applications, rather than exploring their potential to provide an investigation space for mathematical concepts, although Lakoff and Nunez (2001) promote the use of robots in mathematics education as a means of physically embodying mathematical concepts.

Tall et al. (2001) assert that advanced mathematical thinking involves a combination of geometrical and symbolic thinking. Integrated mathematical software that combines dynamic geometry with computer algebra therefore provides a suitable environment for this kind of thinking. One such freely available software package that is rapidly gaining popularity is GeoGebra (see http://www.geogebra.org, and Hohenwarter & Preiner, 2007). However, integrated mathematical software on its own may not be sufficient for effective mathematical learning with some contemporary students because they may find it hard to understand mathematical concepts, and therefore less motivating, by exploring them only within a virtual environment.

Within the interaction between the physical environment of robotics and the virtual environment of GeoGebra the physical environment is easier for students to relate to whilst the virtual environment allows for a greater expression of mathematical language. Therefore confidence and interest in using mathematical language is encouraged via the interplay between these two environments and the social

* Corresponding author. Tel.: +358 403564280; fax: +358 132513564.
E-mail addresses: Lenni.Haapasalo@uef.fi (L. Haapasalo), Peter.Samuels@bcu.ac.uk (P. Samuels).

[1] See http://mindstorms.lego.com/en-US/default.aspx, and the so-called 3-Motor Chassis robot (cf. Fig. 1) discussed more closely in this paper at http://www.nxtprograms.com/3-motor_chassis/index.html. These sites, as all other sites referred in this article have been accessed on 02.02.2011.

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interaction created by collaborative problem solving. This approach is similar to the deconstruction and reconstruction of the locus of movement discussed by Yerushalmy and Shternberg (2005).

Samuels and Haapasalo (submitted for publication) give an overview of three available small robot environments, from which we represent a simple LEGO Mindstorms NXT robot known as the 3-Motor Chassis robots have the capability to perform multiple input and output functions controlled by a netbook with Bluetooth. A netbook also has the capacity to run GeoGebra and the LEGO Mindstorms NXT software. The basis for GeoGebra animations of this robot is their projection onto a horizontal plane, as shown in Fig. 1.

Let us consider an example where a robot has to be steered through three given points in a horizontal plane. Even though this is a relatively simply formulated problem, it can yield a rich challenge in geometric and algebraic problem solving. It can also be formulated as a mathematical modelling problem with many design challenges (which will be discussed later). Calculating the exact angle of rotation of the wheels and distance of translation required to move from one point to other, for example, produces a complex set of five simultaneous equations requiring careful choice of step to solve in the most efficient way. Because in this paper our focus is neither on calculating the parameters nor explaining how to input them into the Mindstorm NXT software, we refer to (Samuels, 2010) where the mathematics behind this problem is discussed in detail. Instead, we would like to illustrate how GeoGebra can be used to determine the angle in rotation robot has to take and the distance of translation to a certain point. For that purpose a free animation Robt11.ggb is available from http://www.geogebra.org/en/wiki/index.php/Robotics. From this animation anyone who has a basic familiarity with GeoGebra can explore simplified situations by removing components, for example, which could then be used with students as scaffolding exercises towards the full problem (see below).

The screenshots in Fig. 2 and Fig. 3 are taken from that animation when mathematical representations have been purposely hidden. It is simple to play with the sliders to try to steer the pivot wheel of the robot through the given points. The position of the pivot wheel has been animated as a sequence of dots using the point tracing functionality. The values of the variables on the sliders can then be entered directly into the LEGO NXT program to make the robot move through the single point physically.

Fig. 3 illustrates the same animation with numerical and algebraic representations. It also clarifies how GeoGebra deals for *instrumentation* and *instrumentalization*. The former means that technology is used to do mathematical actions, whilst the latter means that technology is shaping also the mathematical objects under consideration, and how they appear for the user. Thus, not only preparing but also using the above-mentioned animations, for example, promotes both types of processes. We will use the term *instrumental orchestration* of Trouche (2004) in a wide sense, meaning the instructional measures to scaffold students within those processes.

We now discuss the pedagogical value of this kind of problem-solving environment keeping in mind seven challenges (Chapters 1 to 7) of instrumental orchestration, represented by Haapasalo (2008), and re-ordered here to fit the logical structure of this article:

- Chapter 1 introduces the theory of learning by design,
- Chapter 2 revitalises the argument for sustainable heuristics,
- Chapter 3 discusses the promotion of collaborative social constructions,
- Chapter 4 introduces solid theories that link conceptual and procedural knowledge,
- Chapter 5 describes the dilemma between systematization and minimalism,
- Chapter 6 discusses how to relate instructional design and assessment to instrumental genesis,
- Chapter 7 applies business principles to shift the bad social reputation of mathematics and an over-instrumentalized approach.

We emphasize the main ideas behind these chapters rather than representing mathematical contents in detail. Instead, we provide supporting examples within this classification from the observations and interviews made in different projects and competitions, such as by Petre and Price (2004) who give, in their words, “examples of children independently identifying and understanding principles, concepts, and elements of practice that are fundamental to programming and engineering. It describes further how secondary school students working in teams learned that this programming and engineering knowledge has a social context.”

2. Chapter 1: learning by design

We will begin with this challenge to avoid possible misinterpretations concerning our quite simple problem-solving environment above. Of course, the starting point that “a robot should go through three given points” does not sound appropriate without a *real* context appearing psychologically meaningful for the student. One of the students of the second author designed the following problem environment:

(P1) Astronauts used a vehicle to take samples on several different places of the moon surface. When coming back to the spacecraft they noticed they forgot a very important device at some point. They do not have fuel left to make another journey with the vehicle to look for the device, so they have to program a robot to do the job.

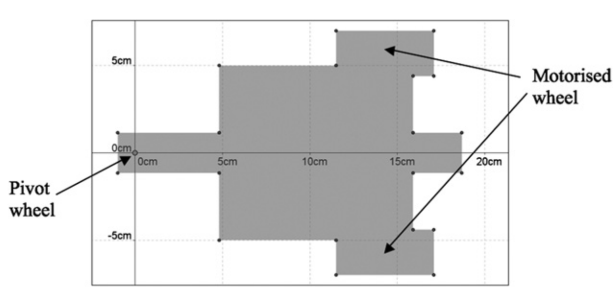

Fig. 1. Horizontal projection of a LEGO Mindstorms NXT 3-Motor Chassis robot in GeoGebra.